

CAN MIRA VARIABLES TELL US THE CHEMICAL ABUNDANCES IN STELLAR SYSTEMS?

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Abstract. A period-metallicity relation for oxygen-rich Miras derived from globular clusters is applied to similar variables in the galactic Bulge. The metallicity distribution in the Bulge thus obtained is in good agreement with that derived from K giants. This suggests that the periods of Miras are useful indicators of metallicity distributions, at least in old systems such as galactic bulges. For systems such as the LMC the situation is not yet clear.

1. Introduction

Whilst detailed, element by element, abundance analyses can now be extended to relatively faint stars, the overall metallicity of a star remains an important characteristic. Even to determine this directly for very faint stars remains a formidable problem. This is especially so when we wish to measure the spread of metallicities within a given system, since this evidently requires data on a large number of stars. In the present paper we suggest that the periods of Mira variables when suitably calibrated can provide this type of abundance data for old stellar systems such as the Bulge region of our own Galaxy. This is of particular interest since the period determination of Mira variables in the bulges of nearby galaxies, as well as in highly obscured regions of the Bulge of our own Galaxy, is now within reach.

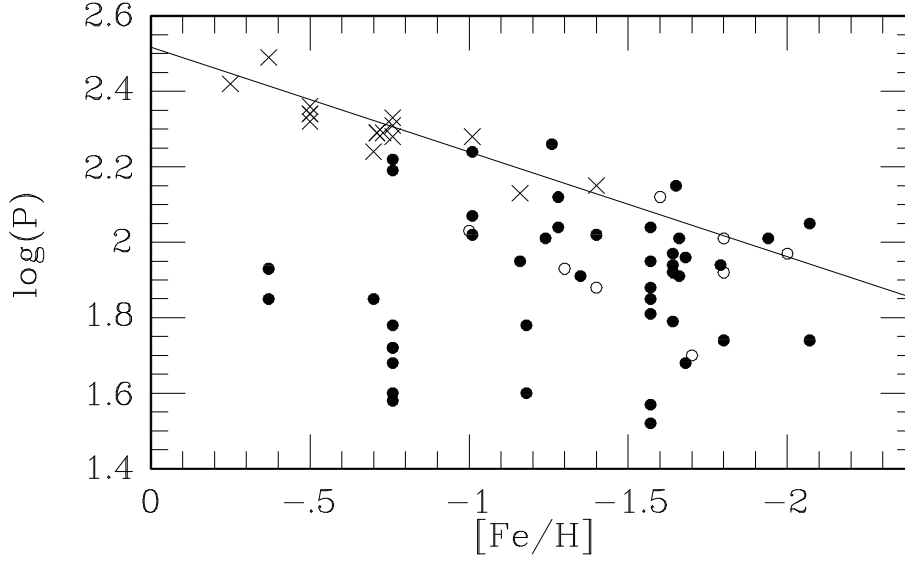


Figure 1. The pulsation period (in days) of variable stars is shown as a function of their $[\text{Fe}/\text{H}]$. Cluster Miras and SRs are shown as crosses and filled circles, respectively. Open circles represent field SRs with spectroscopically determined $[\text{Fe}/\text{H}]$ values.

2. The Mira Period-Metallicity Relation

It has long been known that Miras (in the present paper we are only concerned with oxygen-rich Miras) are highly evolved, old, low mass stars and that their kinematics are a function of period (e.g. Feast 1963). This indicates that the period of a Mira in the general field is a function of metallicity or initial mass (or both). It is not possible to address this problem further in the general field since the complexity of Mira spectra has so far precluded direct spectroscopic measurements of metallicity for them. However, it is known (Feast 1981) that for those Miras which are members of globular clusters there is a relation between the Mira period and the metallicity of the cluster. This relation was quantified (Feast 1992) to $[\text{Fe}/\text{H}] \propto 3.6 \log P$ (where P is the period).

The presently available data are shown in fig 1. Here the log of the period is plotted against metallicity, conventionally denoted as $[\text{Fe}/\text{H}]$, for Miras and semiregular (SR) variables in globular clusters. The data used are primarily from Frogel and Whitelock (1998), details kindly made available by Dr J. Frogel. Some additional SR variables in globular clusters are also included in the plot as well as two additional cluster Miras, V16 in NGC 362 (Lloyd Evans 1983) and V1 in NGC 121 (an SMC cluster). The open circles represent SR variables in the field of the galactic halo for which there are spectroscopic determinations of $[\text{Fe}/\text{H}]$ available (Preston and Wallerstein

1963, Luck and Bond 1985, Leep and Wallerstein 1981, Giridhar *et al.*, 1998, 1999), taking means where necessary. In a given globular cluster the SRs lie along an evolutionary track (or more precisely an isochrone), increasing period going with increasing luminosity (Whitelock 1986). For metal-rich clusters the AGB track terminates with the Miras (if any) in the cluster. Evidently an evolutionary track in fig 1 is vertical. The sloping line shown has been drawn by eye to characterize the longest period at each metallicity and hence may be taken as indicating the end-point of AGB evolution at each metallicity. The slope of the line was as determined in the earlier work on Miras (Feast 1992). Various linear fits to the Mira data are possible depending on how the observations are weighted and the adopted relative errors in the two co-ordinates. The line shown however, seems satisfactory for the present purpose as a fit to the Miras, and has the advantage of giving some weight to the upper limit for the low metallicity SR variables. In the lower metallicity clusters there are no Mira variables as normally defined, but the SR variables near the sloping line are presumably in an equivalent phase of stellar evolution to the Miras in the more metal-rich clusters. The line is given by the relation:

$$[\text{Fe}/\text{H}] = 3.60 \log P - 9.06. \quad (1)$$

Figure 1 thus indicates that, at least in globular clusters, the period of a Mira is a good indicator of metallicity.

Frogel and Whitelock (1998) have shown recently that, within the inevitable uncertainty of small number statistics, the Miras in globular clusters have another useful property. This is that the ratio of the number of Miras in a cluster to the total luminosity of the cluster in the infrared (at K , $2.2\mu\text{m}$) is independent of metallicity (over the range of metallicities for which cluster Miras are found). These results suggest that if the cluster $[\text{Fe}/\text{H}] - \log P$ relation is applicable to a stellar system, not only will it yield the range of metallicities in the system, but also, the relative numbers of Miras of different periods will provide a useful estimate of the frequency distribution of these metallicities in the parent population.

3. Application to the Galactic Bulge

We can now test and discuss the cluster $[\text{Fe}/\text{H}] - \log P$ relation by applying it to Miras in the galactic Bulge. To do this we have combined data on Miras in the two Baade windows, Sgr I and the NGC 6522 field. Combining the data from the two fields improves the statistics considerably.

In carrying out an analysis such as this it is essential that the results are not biased by selection effects. Although the infrared (K) and bolometric luminosities of Miras increase with increasing period, the visual luminosity

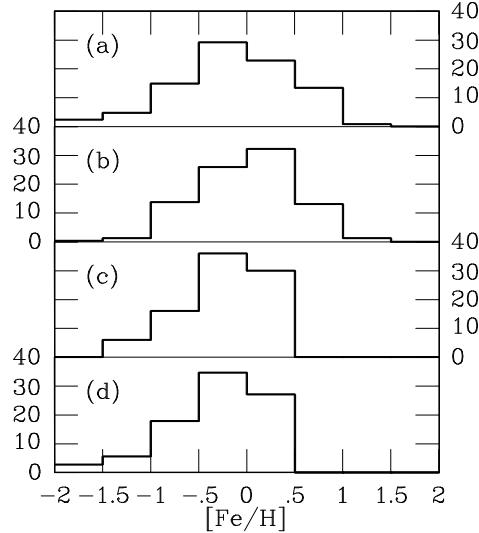


Figure 2. Histograms of the metallicity distribution of galactic Bulge stars: (a) Miras (as derived from periods); (b) K giants (Sadler *et al.*); (c) K giants (McWilliam and Rich); (d) Miras renormalized as described in the text. The samples have been normalized to the same effective total number of objects.

decreases because the longer the period, the cooler the star. The initial South African observations in the Sgr I field were on blue sensitive plates and the variables discovered on them (Oosterhoff and Ponsen 1968) were mainly of short period. The later work was on red sensitive plates and the proportion of longer period Miras found was larger (Lloyd Evans 1976). Later still Miras detected by IRAS extended further the long period coverage (Feast 1986, Glass 1986, Glass *et al.*, 1995), see Glass *et al.* fig 2. For the NGC 6522 field we have used the periods from Lloyd Evans. This samples seems essentially complete as it includes all except one of the IRAS Miras in the field. In the case of the Sgr I field we use the data from Glass *et al.* which includes the IRAS Miras together with periods from Lloyd Evans for Miras not observed by Glass *et al.*

Where necessary, in this first application, we simply extrapolate equation 1 linearly to higher metallicities, outside the range of the globular cluster Miras. The consequences of this extrapolation will be discussed below.

The frequency distribution of Mira metallicities derived in the above manner may be compared with the frequency distribution of metallicities of K giants in the NGC 6522 field. For this we have used the values of $[Fe/H]$ derived by Rich (1988) for 88 stars (his solution 1 rescaled according to equation 6 of McWilliam and Rich (1994)), and the $[Fe/H]$ values for

the 262 Bulge K giants derived from low dispersion spectra by Sadler *et al.* (1996) and plotted in their fig 11. Figure 2 shows this comparison. The Mira distribution (total number of stars = 112) and the Sadler *et al.* K giant distribution have been scaled to match the total number of K giants in the Rich sample.

Figure 2 shows that the distributions of the Miras and the K giants from Sadler *et al.* agree very well. Sadler *et al.* quote a mean $[\text{Fe}/\text{H}]$ for their sample of -0.11 ± 0.04 with a dispersion of $\sigma_{[\text{Fe}/\text{H}]} = 0.46$ whilst the Miras give a mean $[\text{Fe}/\text{H}]$ of -0.16 ± 0.06 and $\sigma_{[\text{Fe}/\text{H}]} = 0.59$. These values are not significantly different for the two samples. The Mira metallicity distribution agrees well with that of the Rich sample except at the high metallicity end. The agreement of the Mira distribution with either the Rich or the Sadler *et al.* sample would be made considerably worse by moving the Miras one box in either direction.

There are at least three possible (alternative) reasons for the apparent lack of agreement of the Miras with the Rich sample at the high metallicity end.

(1) At the high metallicity end, both the Mira and the Sadler *et al.* distributions depend on extrapolations of the (entirely different) metallicity calibrations used. One can to some extent circumvent possible problems with the extrapolation by simply comparing the number of Rich K giants with $[\text{Fe}/\text{H}] > 0.0$ with the number of Miras in this same metallicity range. There are 30 Rich K giants with $[\text{Fe}/\text{H}] > 0$, whilst the scaled number of Miras is 37. These numbers are not statistically different. Thus the results do not preclude the possibility that the frequency distributions of Rich K giants and Miras are the same at all metallicities. A change in the slope of the $[\text{Fe}/\text{H}] - \log P$ relation at high metallicities would suffice to bring the two distributions into satisfactory detailed agreement.

(2) On the other hand there also seems some possibility that the Rich K giant distribution might be deficient at the metal-rich end. This would occur if all the very metal-rich K giants were below Rich's magnitude limit. In other words, in the magnitude range observed by Rich such metal-rich stars might be late M giants. In that case a better comparison between the Rich stars and the Miras is obtained by omitting the long period Miras which are predicted to have $[\text{Fe}/\text{H}] > 0.5$, and rescaling. The result of doing this is shown in fig 2(d). The agreement of the two distributions is improved in this way.

(3) Finally, it should be borne in mind that the apparent difference between the Rich K giant distribution and the other two distributions may be simply a result of small number statistics.

Our conclusion regarding the Mira metallicity distribution differs somewhat from that of Frogel and Whitelock (1998). They also obtained a metal-

licity distribution from the periods of Bulge Miras (their fig 8). This agrees less well than ours with the K giant distribution (either that of Rich or that of Sadler *et al.*) both at high and low metallicities. The main reason for this is that Frogel and Whitelock used a much steeper $[\text{Fe}/\text{H}] - \log P$ relation than is consistent with our fig 1. This is due to their relation being drawn to take into account some metal-rich SR variables which are below the limiting line that the Miras actually fit.

At first sight our conclusions seem at odds with another of the results derived by Frogel and Whitelock. They concluded that integrated over all metallicities, the number of Miras per giant brighter than $M_{\text{bol}} = -1.2$ in the NGC 6522 field was less than in globular clusters. However, at the present time this result must be considered quite uncertain. The result depends partly on a comparison of the total number of Miras in the NGC 6522 field with the number of M type stars brighter than a certain apparent magnitude in that field and the assumption that stars of the same apparent magnitude have the same absolute magnitude. Whilst this is true for a globular cluster it is not so for the galactic Bulge since in the Bulge the stars are significantly spread along the line of sight. The spread (~ 2 mag) in the Mira infrared-PL relation in the Sgr I field (Glass *et al.*, 1995) compared with the narrow PL relation in the LMC (Feast *et al.*, 1989) is evidence for such a spread. This will evidently complicate any analysis. In addition the relative numbers of Miras to giants in globular clusters is not calculated directly but derived from a theoretical relation between the total luminosity of a cluster and the number of giants brighter than a certain value. Whilst our own results are in satisfactory agreement with the hypothesis that the ratio of numbers of giants to total luminosity does not depend critically on metallicity, the absolute calibration of this ratio depends on theoretical giant branch isochrones.

4. Is the Mira Period-Metallicity Relation Universal?

The evidence just discussed suggests that Mira of a given period in the galactic Bulge have the same metallicity as Miras of that period in globular clusters. Is this result universal?

There is evidence of differences between Miras of the same period in different environments. Glass *et al.* (1995) have compared the period - infrared colour relations for Miras in the Sgr I field with those in the LMC (their fig 4). There is some uncertainty in these relations due to uncertainties in the correct interstellar absorption to adopt. However, no adopted relative absorption between the LMC and Bulge fields, with a standard reddening law, will bring all the period-colour relations into agreement. If we make the $P - (J - K)$ relations agree then $H - K$ is redder in Sgr I than the

LMC at a given period and $J - H$ is bluer. In view of this result a useful quantity is:

$$\phi = (J - H)_0 - (H - K)_0. \quad (2)$$

This quantity is rather insensitive to the adopted interstellar reddening. There is no significant difference in ϕ between the Bulge Miras and those in globular clusters ($\Delta\phi(Glob.Cl. - Bulge) = +0.03 \pm 0.03$). However, a difference, varying somewhat with period, does exist between the Miras in the LMC and those in the Bulge. Using the stellar models of Bessell *et al.* (1989), Feast (1996) used this difference in ϕ to deduce that the LMC Miras at a given period were metal deficient compared with those in the Bulge by ~ 0.4 dex. Differences in ϕ reflect differences in the strength of H_2O bands at a given period. This will be affected not only by differences in the atmospheric [O/H] ratio but also by any difference in the [C/H] ratio (due for instance to dredge up processes) since oxygen is preferentially locked up in the CO molecule. Thus whilst it seems safe to assume that the LMC Miras are deficient in oxygen compared with those in the Bulge the exact amount is still uncertain. Whether an oxygen deficiency implies a deficiency in other elements (e.g. iron) is also uncertain. As summarized by Gilmore and Wyse (1991) young objects in the LMC seem to have a lower [O/Fe] than similar galactic objects but it is not known if this extends to older stars. It remains unclear therefore whether the LMC Miras would fit the period-metallicity relation of fig 1. However, it is noteworthy that the Mira in the SMC globular cluster NGC 121 which is plotted at $\log P = 2.15$ (Thackeray 1958) and $[Fe/H] = -1.4$ (Stryker *et al.*, 1985) in fig 1 fits the adopted relation closely. This suggests that at least at short periods the Magellanic Cloud Miras fit the adopted relation ¹.

The period distribution of O-rich Miras in the LMC peaks at shorter periods than in the galactic Bulge. Thus the O-rich LMC Miras in Table II of Hughes and Wood (1989) together with equation 1 above yield a distribution of LMC O-Mira metallicities peaked between an [Fe/H] of -1.0 and -0.5 . However, unlike the galactic Bulge there are also carbon Miras in the LMC and it is not entirely clear how the overall metallicity distribution would be affected by taking these into account, even if equation 1 applies to the LMC O-Miras.

¹(1) There is also a difference in the $(K_0 - m_{bol}) - \log P$ relation between the LMC and the Bulge Miras which is probably a metallicity effect (see Feast and Whitelock 1999).

(2) The value of ϕ at a given period is also a function of the pulsation amplitude (Whitelock *et al.* in preparation). This is believed to be due to the strengthening of the H_2O bands as the atmospheric extension is increased by pulsation. It is unlikely that this is the cause of the LMC - Bulge difference.

5. Conclusions

Our main conclusion is that applying the metallicity scale for Miras as a function of period set by globular clusters, to Miras in Bulge fields, leads to a metallicity distribution in good agreement with that shown by Bulge K giants in the sample of Sadler *et al.* The agreement is also good with the metallicity distribution of the (revised) Rich K giant sample except at the very metal-rich (long period) end where a significant extrapolation of the derived cluster period-metallicity relation is required. A modification of this extrapolation could remove this discrepancy. Alternatively the K giant sample of Rich might be deficient in very metal-rich stars. Thus at least in the Bulge, the Miras provide a metallicity tracer for a significant population.

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